

NO LARGE BRIGHTNESS VARIATIONS ON NEREID

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The small Neptunian satellite Nereid sweeps around its primary in a highly eccentric, distant orbit. Its rotational state is entirely unknown. Telescopic and spacecraft observations of variations in its brightness, which offer clues on its rotational period, support entirely different conclusions. Two independent groups of ground-based observers both reported periodic changes in Nereid's brightness of a factor of 4 during a single night, with a period of 8-24 hours¹⁻². However, observations by Voyager 2 of Nereid in 1989 show no evidence of any variations in brightness greater than 15% over a 12-day period³. Our own recent observations of Nereid with the 200-inch telescope on Palomar Mountain over three contiguous nights show no evidence for the large photometric variations seen by earlier observers. Total brightness variations within a single night are less than 10%. Our results suggest that Nereid may have a long rotational period, perhaps on the order of weeks.

Recent predictions⁴ that Nereid may be in a state of chaotic rotation have sparked debate that the discrepancies between telescopic and Voyager observations may be due to their acquisition at different points in the satellite's orbit. The Saturnian satellite Hyperion has already been shown to exhibit chaotic rotation^{5,6}. For the case of Nereid, is it possible that the large photometric variations occur near the time of Nereid's periapsis, when the satellite is expected to exhibit chaotic motions, while the Voyager observations occur nearer apoapsis, when the satellite would be in a quasiperiodic rotational state? An examination of the timing of previously published observations shows there is no correlation between the amplitude of the variations and the proximity to periapsis (Table 1). Ironically, the observations showing the greatest variations are *farthest* from periapsis. Furthermore, the large amplitude of the ground-based observations presents physical problems. If the photometric variations are due to an elongated shape, the ratio of the shortest to longest principal axes (if the shape of the satellites is modeled as a triaxial ellipsoid) would be 1:4. Similarly, if the variations were attributed to albedo changes on the satellite, the differences would amount to a factor of four. Voyager 2 imaging measurements show that Nereid did not depart from sphericity by more than 20%, and there is no evidence of large albedo variegations (although the entire surface was not imaged)⁴.

We obtained photometrically accurate observations of Nereid on the 200-inch telescope on Palomar Mountain and a CCD imaging device (R-Filter) during three contiguous nights with time resolution on the order of several minutes (Table 2).

About one-third of the images were rejected due to Nereid's proximity to field stars. Each image was biased-subtracted and flatfielded. The integrated flux within an aperture of 6 arcseconds was computed and compared with the integrated fluxes of five standard stars that appeared on the CCD frame on each night. The resulting numbers were then tied to Landolt standard star fields to obtain absolute photometric measurements."

Figure 1 shows our results for the three nights; both individual measurements and nightly averages are depicted. Figure 2 shows these results with previously published observations for comparison. Our observations show no evidence for the large variability in brightness previously reported. During the last two nights, for which we obtained observations every 13 minutes during the full period Nereid was visible from Palomar Observatory (a forest fire prevented all but one hour of observations on June 28, 1995 UT), no brightness changes greater than 0.10 magnitude were observed. Neither is there any evidence of periodicity in the observations. The average brightness of Nereid on the first night was 0.14 ± 0.03 magnitudes brighter than on the last two nights. The last two nights also exhibit decreases of 0.05 - 0.025 magnitude over a five ant{ a half hour period, although these decreases are not statistically significant (Figure 3). The brightness decrease between the first and second nights is too large to be due to solar phase effects. The phase angle changes only 0.03 degrees within this period, and the effect would be an increase rather than a decrease. The most likely explanation for the observed decrease in brightness is rotation.

The natural satellites tend to divide into bodies that rapidly despin to a synchronous state and those that retain their primordial spin state⁸. The few satellites that dwell in the dynamical zone of neither rapid evolution to a synchronous state nor retention of primordial rotation state are particularly important because they may be in chaotic rotation. A description of their dynamical state yields constraining data on the theory of tidal evolution of planetary satellites. The factors contributing favorably to the possibility of a chaotic state of rotation are high orbital eccentricity, non-spherical shape, and a large distance from the primary. These factors make Nereid a prime candidate for a satellite in chaotic rotation^{4,8}; it has by far the highest eccentricity (0.75) of any known natural satellite anti a semi major axis of 355,500 km.

Recent theoretical modeling makes specific predictions about the current state of Nereid's rotation⁴. According to this model, during a two-month period centered around periapsis, Nereid's spin rate is poorly defined because it

changes rapidly. In the few months around apoapsis, the spin state is comparatively well-defined with a period of 1-2 months. Our observations obtained a week from periapsis show no evidence of periodicity, but they do not yield evidence one way or another for chaotic rotation. If Nereid is nearly spherical (a departure from sphericity of only 1% is required for it to be in a chaotic state), and it has small albedo variegations, brightness variations due to rotation - even for chaotic rotation - would be small, similar to those we observed. On the other hand, our measurements are also consistent with a long rotation period. The decrease from the first to the second night could be due to changes in the projected area of a slightly irregular satellite or small albedo variations on a satellite rotating with the one or two month period suggested by the dynamical model. Our measurements are also consistent with a period on the order of a day, if additional maxima and minima occur during daylight. Theoretical models, however, argue against a rotation period this short. In any case, our observations show no evidence of the previously reported large brightness variations exhibited during a single night^{1,2}.

Our observations provide a measurement of the geometric albedo of Nereid at 0.72 μ m. With a phase coefficient of 0.024 magnitudes/degree³, we find an opposition magnitude of 19.02 ± 0.03 , corresponding to a geometric albedo of 0.18 ± 0.05 (0.01 of the error is due to the uncertainty in our photometry, while 0.04 is due to the uncertainty in the Voyager measurement of the radius of 170 ± 25 km). Figure 4 shows our results plotted with Voyager measurements of Nereid's spectrum between 0.41 and 0.56 μ m. The color of Nereid is gray, but the satellite is much brighter than C-type (carbonaceous) bodies, the major class of gray bodies in the Solar System. Its spectrum is most similar to the darkest medium-sized Uranian satellite, Umbriel, and it is most likely composed of an admixture of ice and spectrally neutral, darker (carbonaceous) material.

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Table 1 - Summary of Nereid Observations

Observers	Dates of observation	Days from periapsis	Δmag	period (hrs)	a/b
Schaefer & Schaefer ¹	June 18-26, 1987	-34	1.5	8-?4	0.25
Schaefer & Schaefer ⁹	May, June, July 1988		-1.5	≤ 200	0.25
Bus and Larson ¹⁰	11-15 June; 13-16 July 1988	-8	-0.5	>24	0.63
	June 1989		-0.5	>24	0.63
Williams et al. ²	July 10-18, 1990	0	1.3 ± 0.2	13.6 ± 0.1	0.30
Thomas et al. ³	August 13-25, 1989	+ 24	≤ 0.15	unknown	0.80-1 .0
This study	June 28-30, 1995	+8	≤ 0.10	unknown	

Table 2 - Summary of Palomar 200-inch CCD Observations

Date and Time (UT)	# Images (useable)	Solar phase angle
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28 June 1995	3	0.61
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29 June 1995	18 (10)	0.58
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30 June 1995	22 (17)	0.55
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Figure Captions

Figure 1. The brightness of Nereid on the dates of June 28, 29 and 30. Each solid point represents the brightness of the satellite as derived from a single CCD image. The three nightly averages are shown as open squares.

Figure 2. Our observations (solid points) compared with two sets of previous observations : the Voyager 2 data³, and ground-based telescopic measurements^{1,2}. Previously reported large variations in the brightness of Nereid are not seen in our observations.

Figure 3. Our observations from June 29 and 30 1995 (UT) with corresponding best-fit straight lines. The solid line (June 29) and dotted line (June 30) show no evidence for statistically significant changes in Nereid's brightness, either within or between the individual nights. Previous observational² reported variations in brightness of up to 1.5 magnitudes within a few hours.

Figure 4. The geometric albedo of Nereid derived from our observations, shown with previous measurements obtained by Voyager ³. For comparison, two objects are shown: a typical C(carbonaceous) -type asteroidal, and the Uranian satellite Umbriel¹². Although Nereid's spectrum is similar to carbonaceous objects in that it is flat in the visual regions of the spectrum, it is clearly brighter than these bodies. In the visual, Nereid is most similar to the Uranian satellite, Umbriel, and it is most likely composed of an admixture of ice and darker, gray (carbonaceous) material. (Eighty percent of the quoted errors for Nereid is due to the uncertainty in the Voyager-derived radius; this portion of the error does not effect the relative positions of the points) .

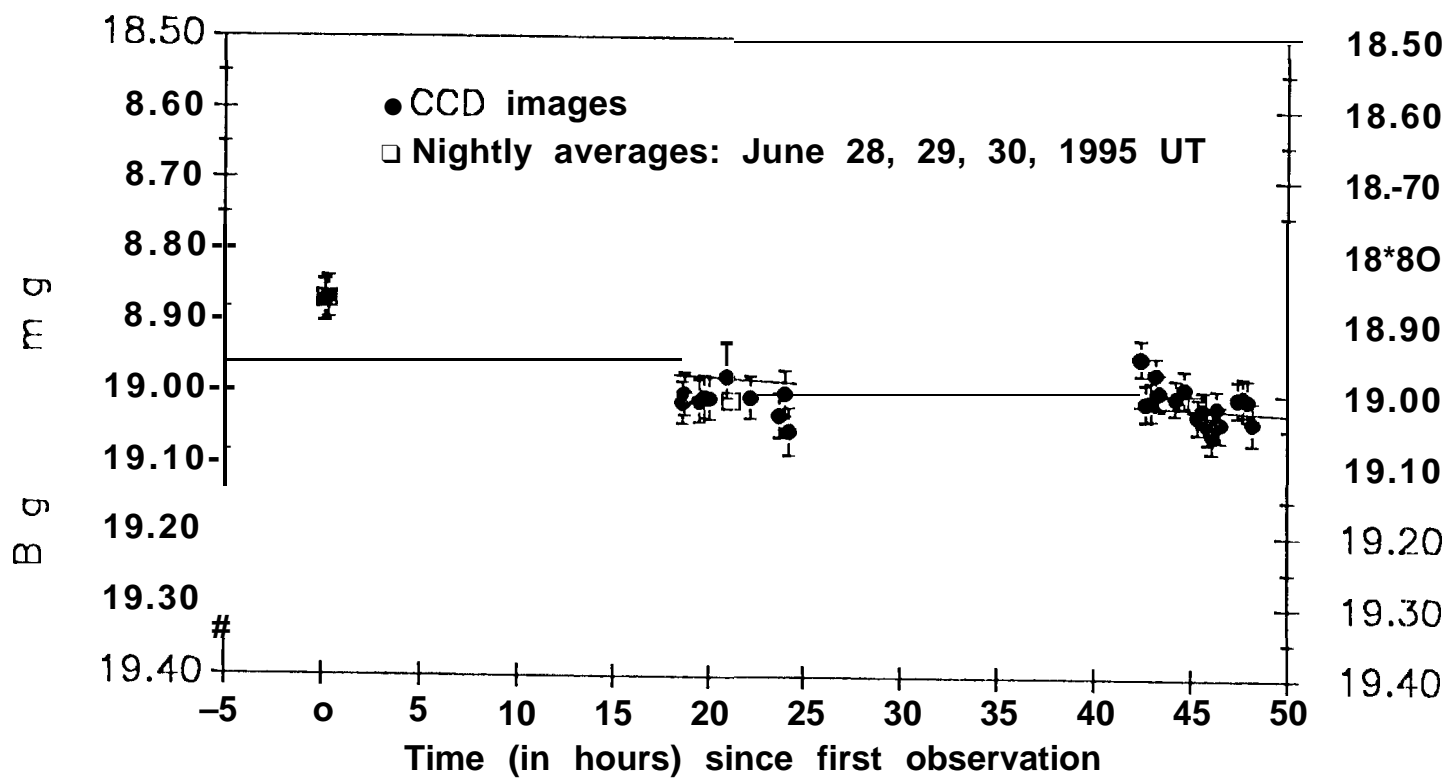


FIGURE 1

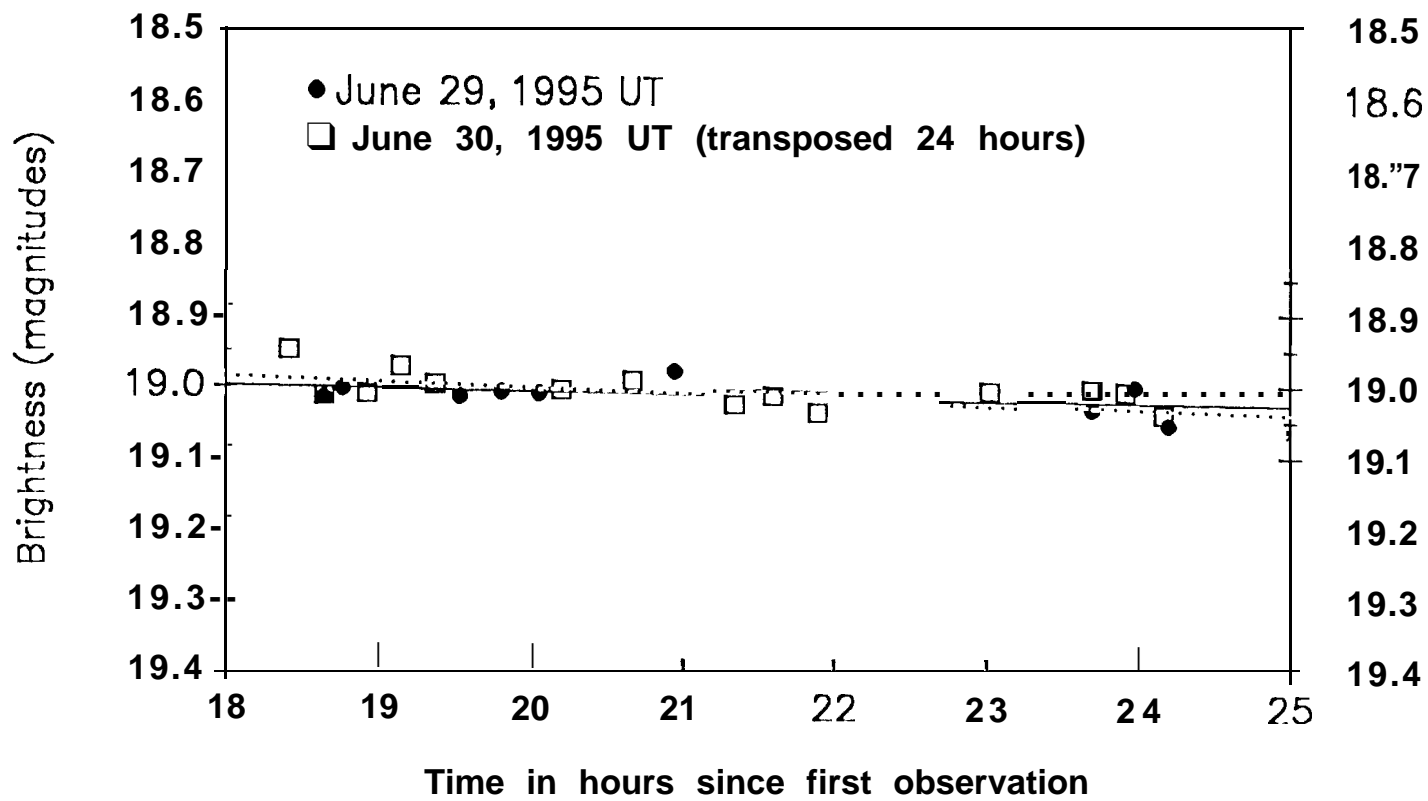


FIGURE 3

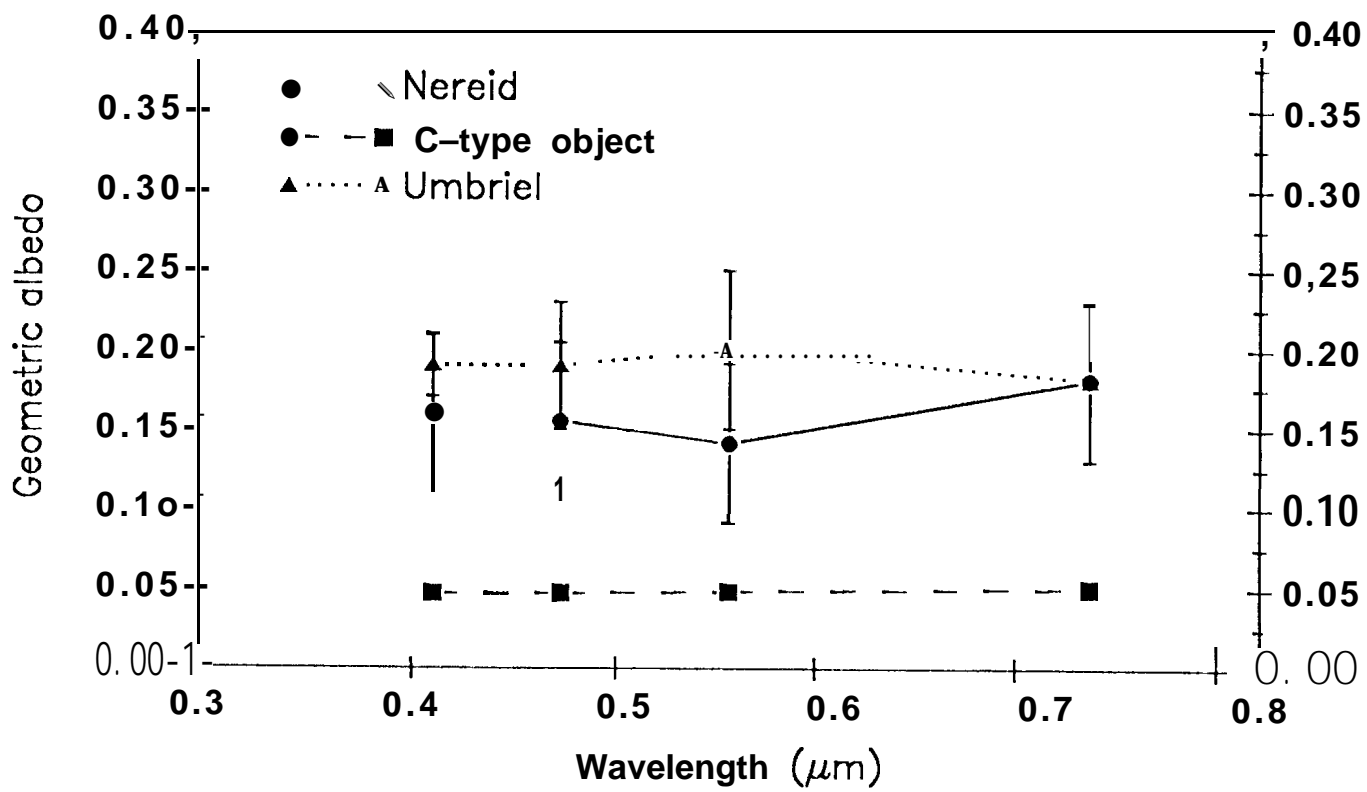


FIGURE 4